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Scintillation-based background rejection methods

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DUNE Low Energy Physics Working Group - August 11, 2021

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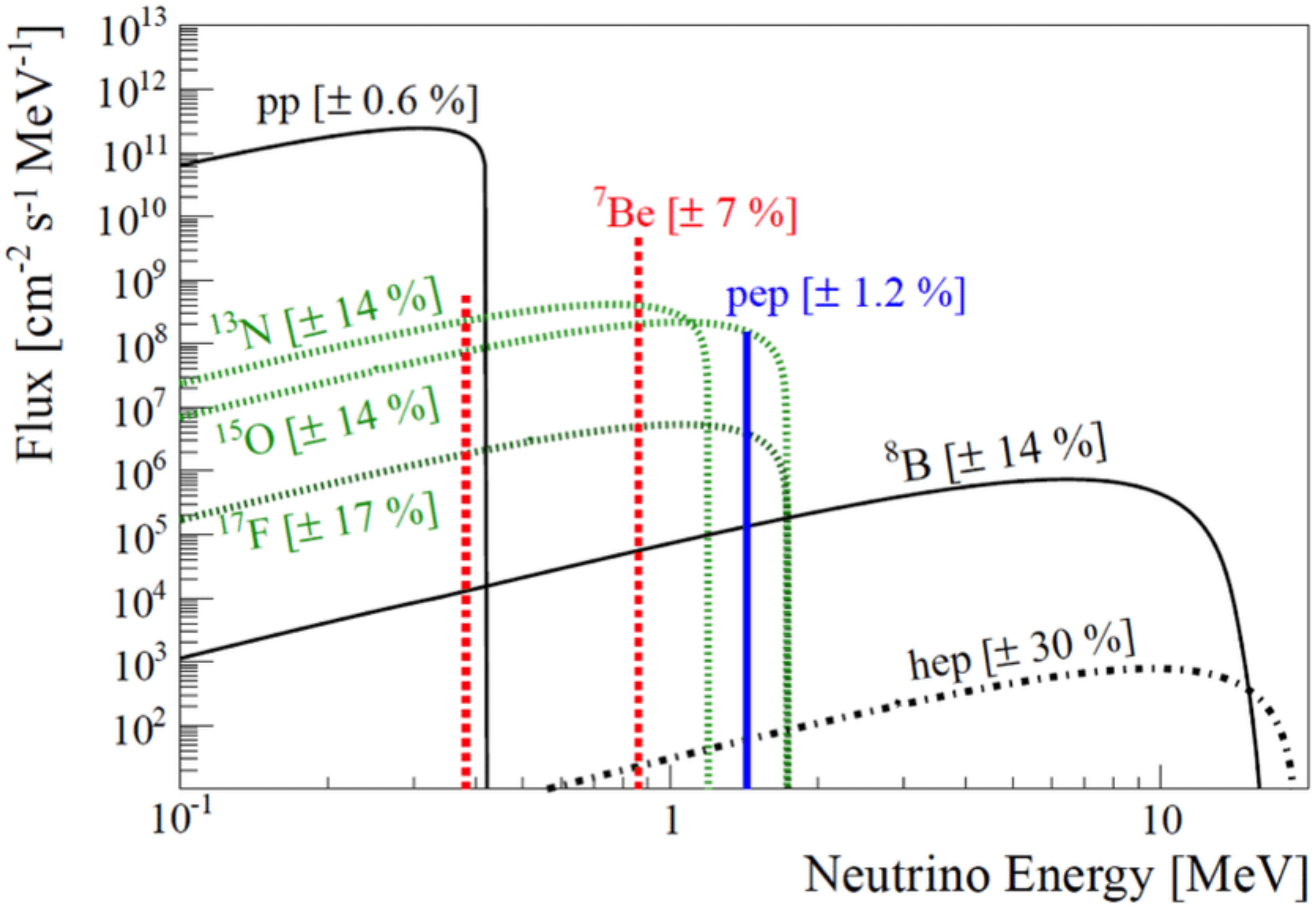
Solar neutrinos in DUNE

Solar neutrinos

DUNE potential



DUNE could deliver world-leading results in solar neutrinos:

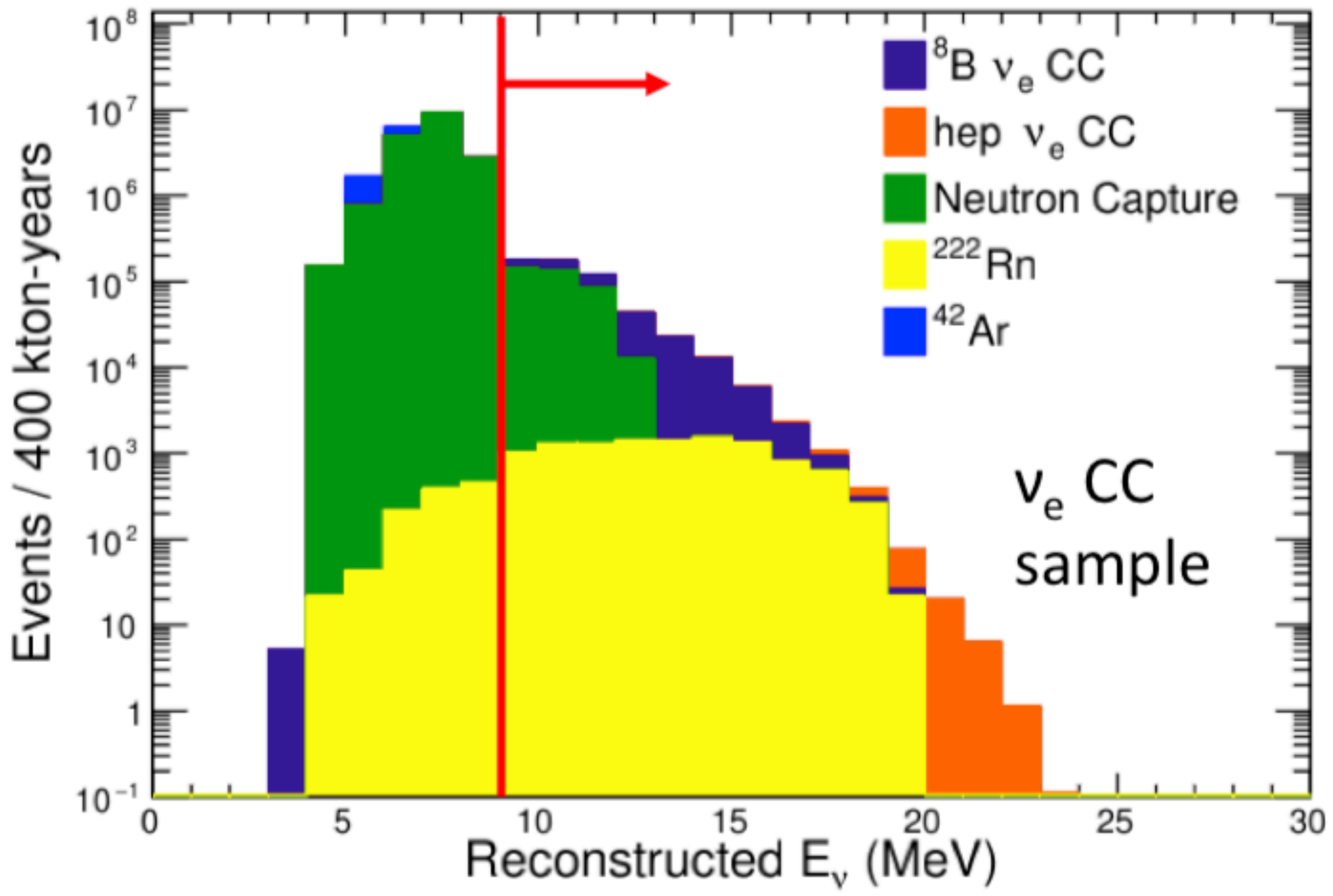
- Precision measurement of the ^{8}B flux
- First observation of the hep flux
- Neutrino-mixing parameters measurements

Solar neutrinos

Previous study

- Dan Pershey studied charge signal from solar neutrinos and background sources
- Identified $^{40}Ar(\alpha,\gamma)$ reactions from ^{222}Rn decays as a concerning background
    - ^{222}Rn uniformly distributed in the LAr
    - α from Rn decay chain absorbed by ^{40}Ar with subsequent γ emission (rare, but too frequent to be negligible)
    - Eγ ~ 15 MeV

Assume 10 mBq/kg of ^{222}Rn
(see Juergen's talk*)*



Idea: use scintillation light to reduce ^{222}Rn backgrounds

Solar neutrinos

Our study

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- Improve solar neutrino signal selection with scintillation-based methods
  - Make use of Pulse Shape Discrimination (widely used in dark matter LAr experiments)
  - Rely on non-uniform distribution of ions from ^{222}Rn decays in the TPC
  - No charge information

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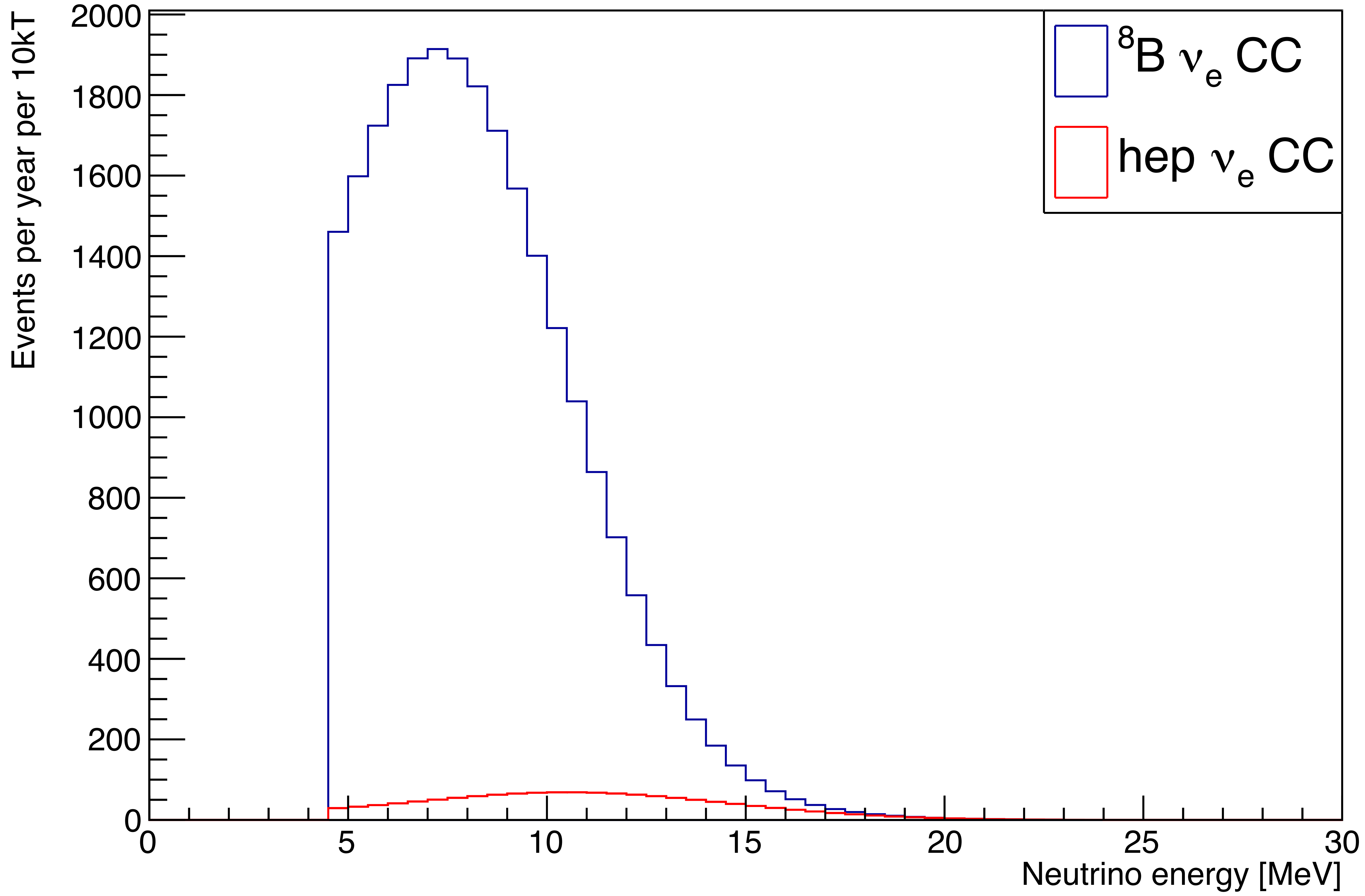
Detector and simulation

Detector and simulation

Event rate in DUNE



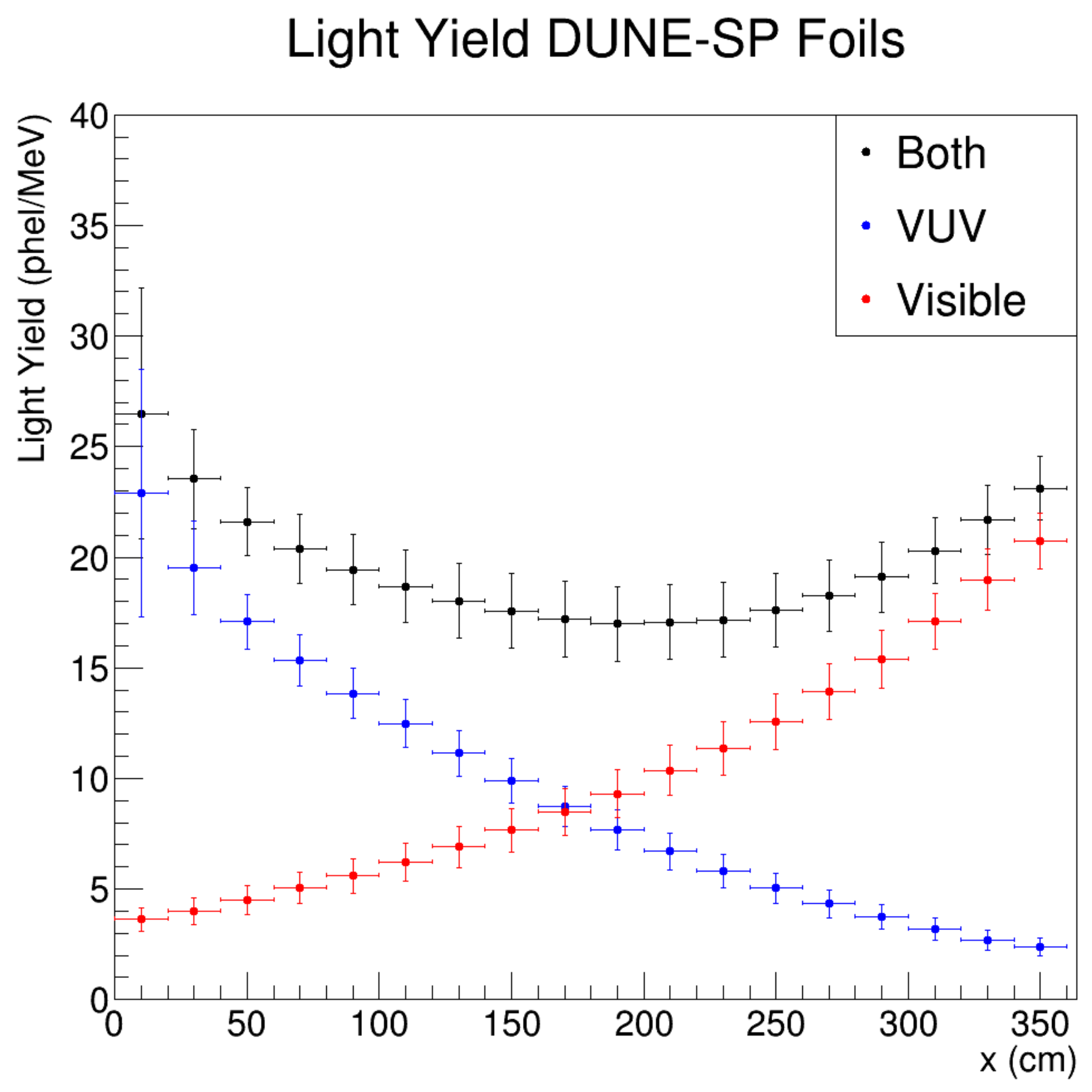
Initial fluxes from
E.Vitagliano, I.Tamborra, G. Raffelt

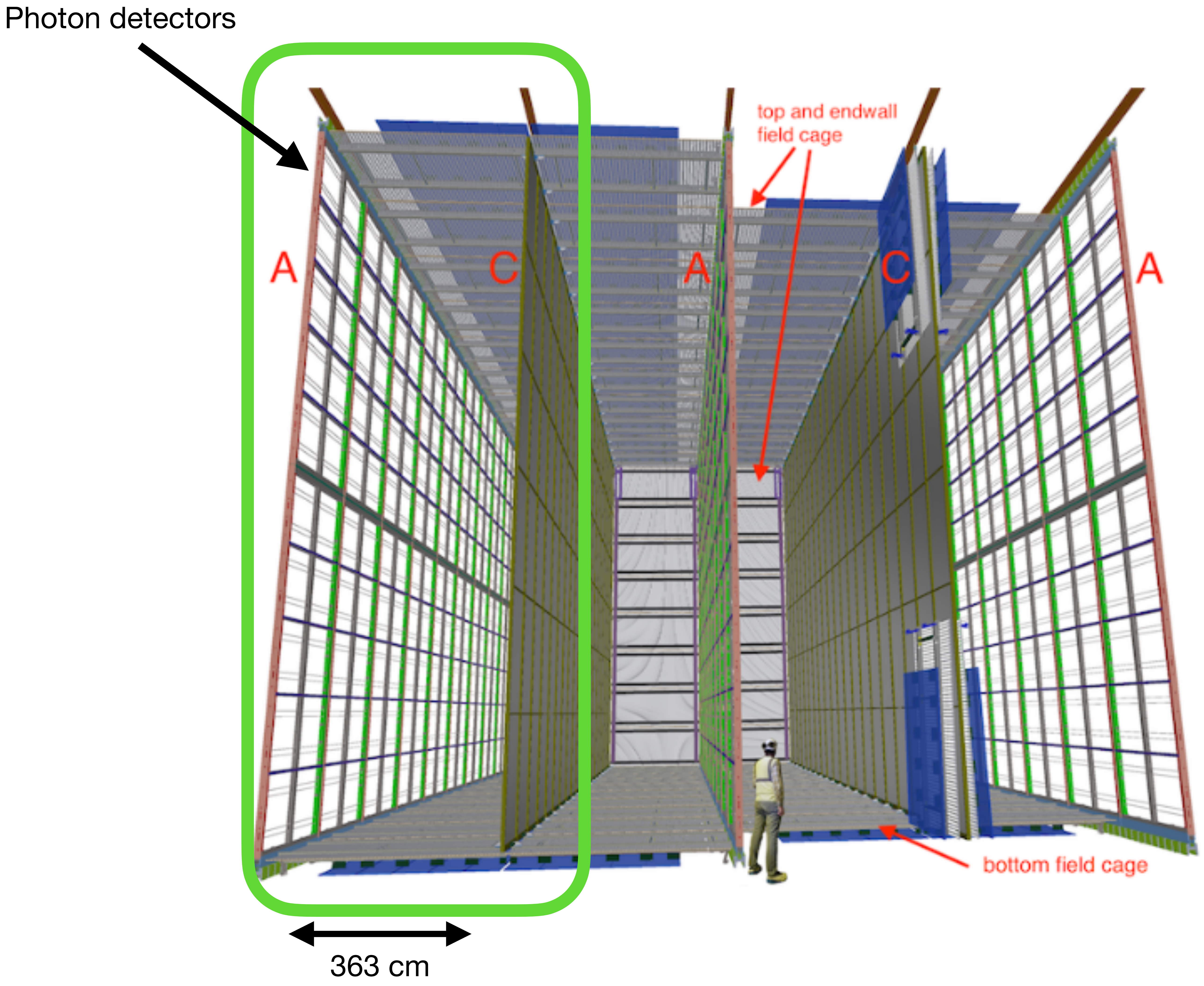
Event rates are computed using SNOwGLoBES (see website)

Detector and simulation

Geometry

- Simulate events in one section of module, between anode and cathode
- Study impact of Xe doping
- Add TPB coated foils at the cathode plane to enhance light collection





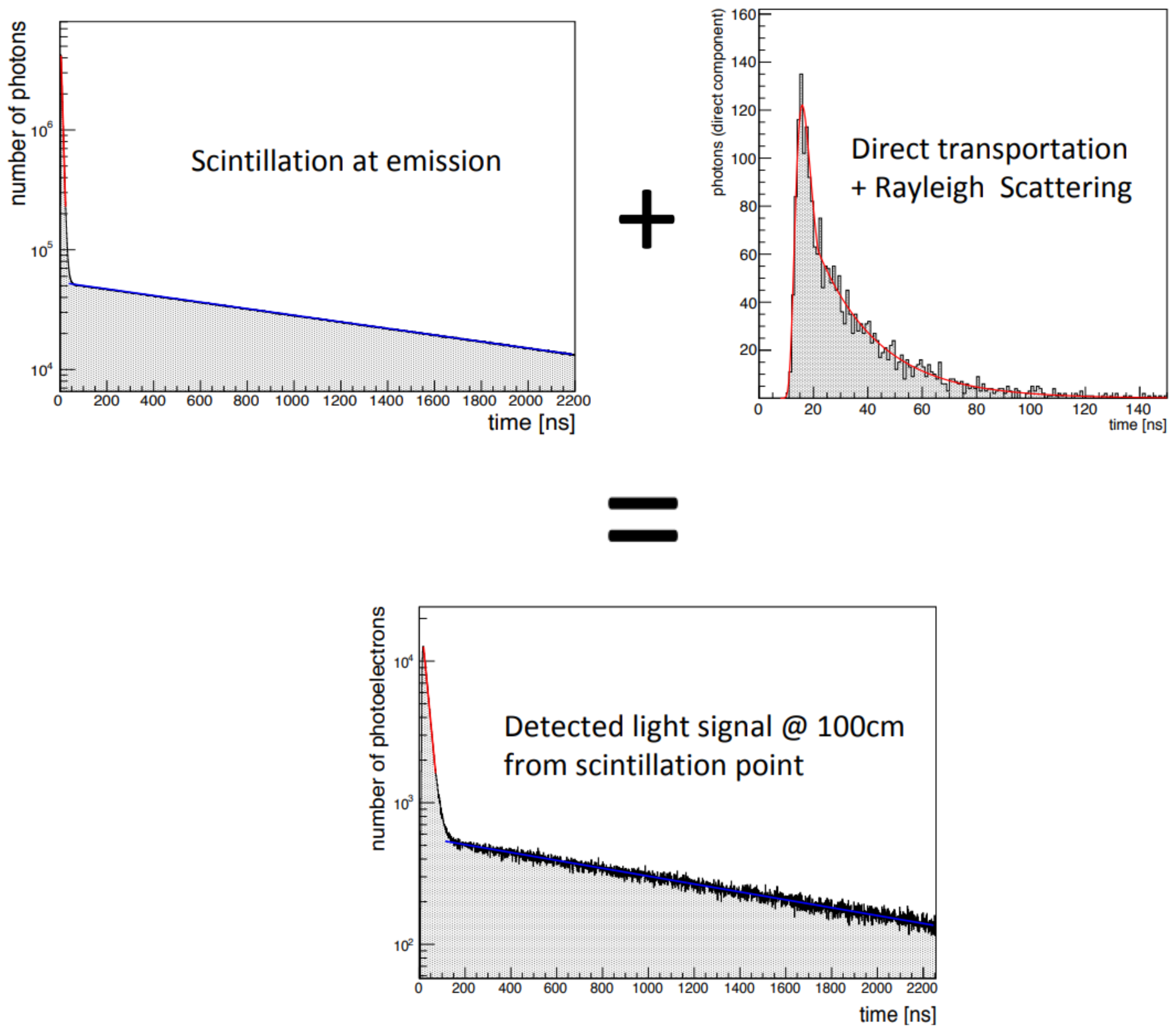
Detector and simulation

Semi-analytic scintillation model

- Geometric prediction of number of incident photons and direct propagation time
- Parametrised corrections accounting for effects of Rayleigh scattering, absorption and reflections

Standard fast optical simulation in DUNE-SP, SBND

(see arXiv:2010.00324 for further details)

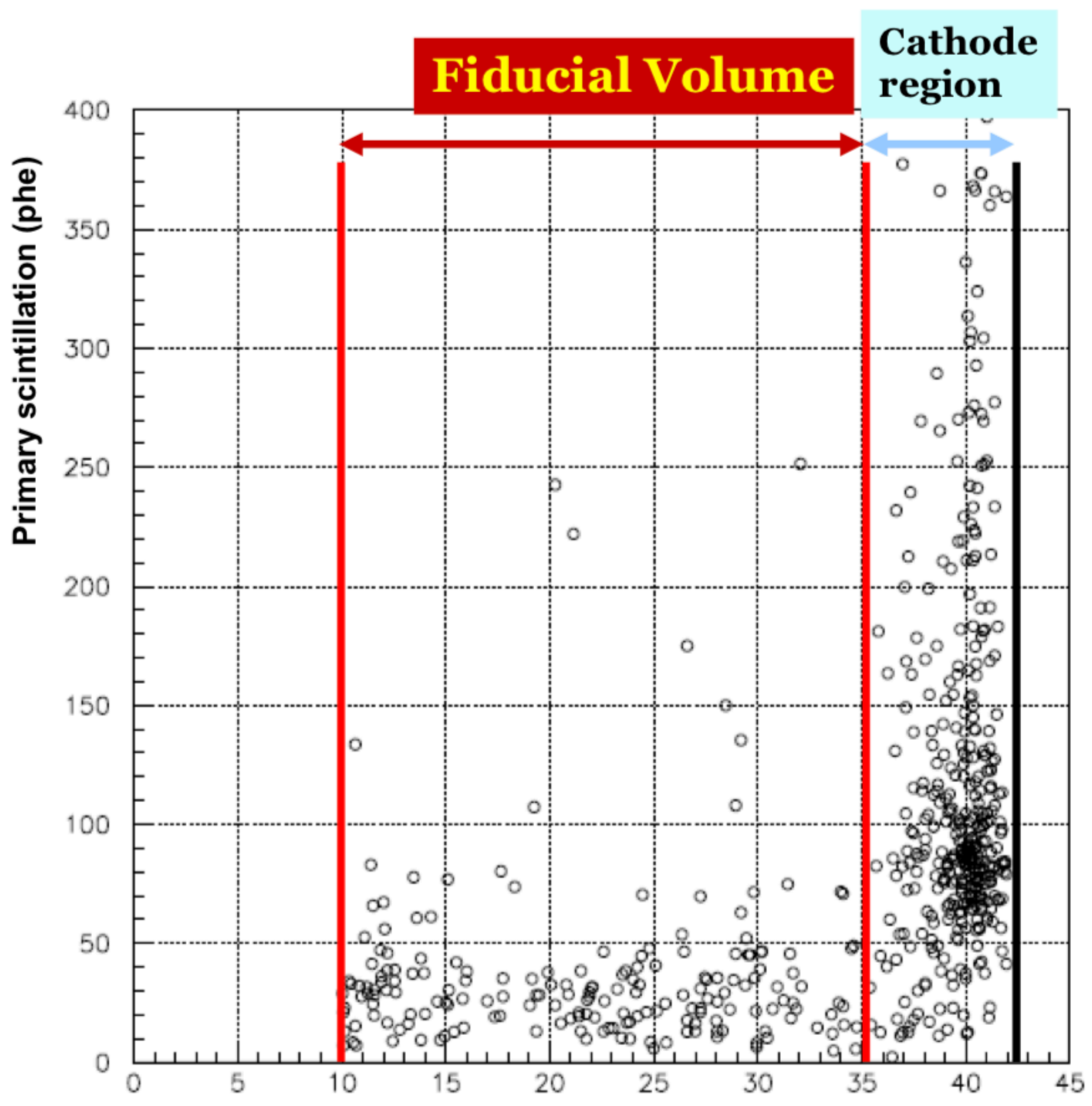


Ion migration model

Ion migration model

Context

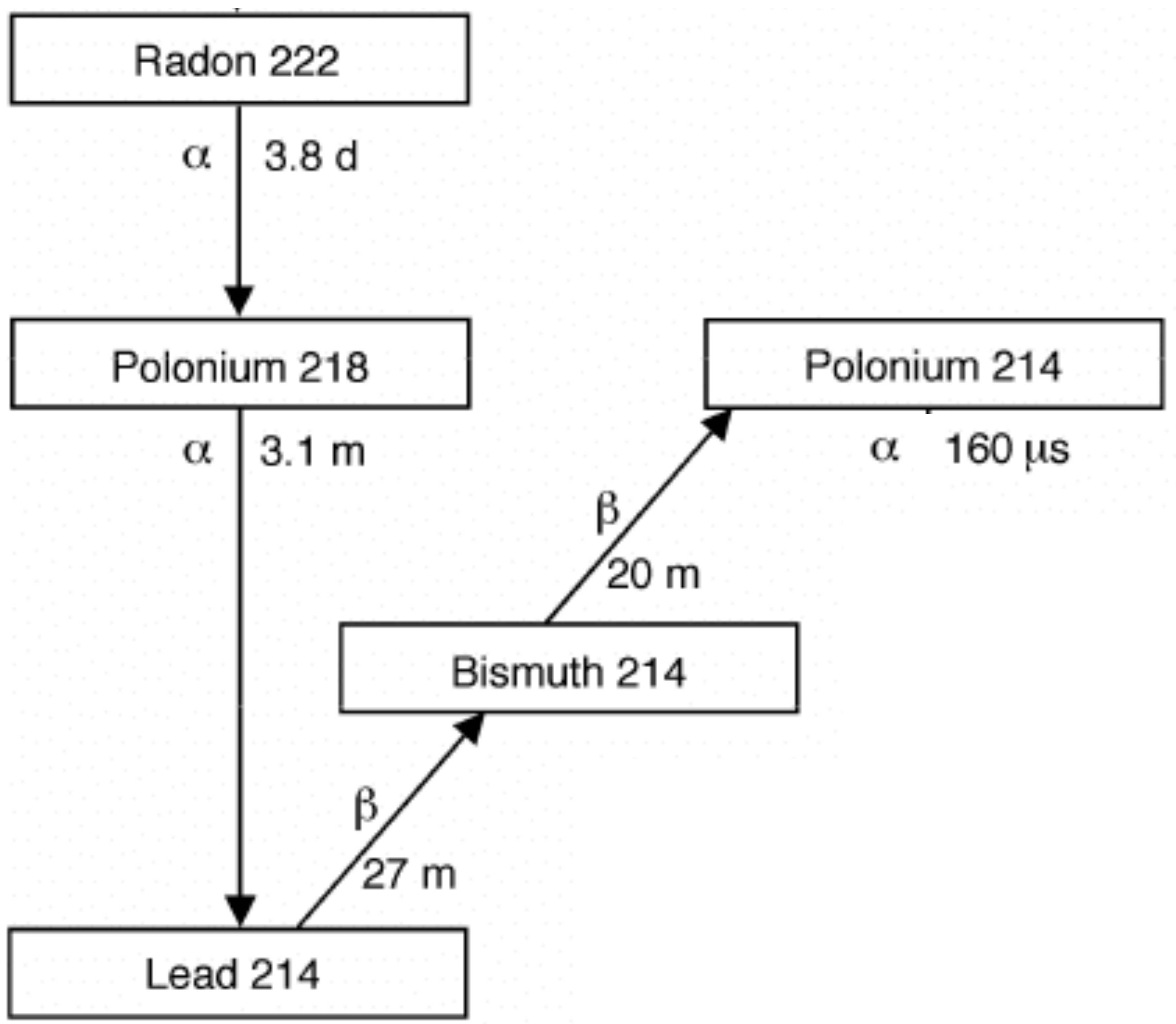
- Some dual phase TPC experiments observed an accumulation of ^{222}Rn and daughters events near the cathode
  - Due to some radon daughters being produced as positive ions
- Can provide a way to discriminate against background if we are able tag events near the cathode
- Need to know the fraction of alpha decays happening at the cathode



Observation by WArP

Ion migration model

Method



- Simulate the decay position of the different elements of the chain
  - The two key parameters are the ionisation fraction and drift velocity
- ^{222}Rn distributed uniformly along x-position with no drift
- ^{214}Po drift neglected due to its short half-life
- Extract the x distribution of alpha decays

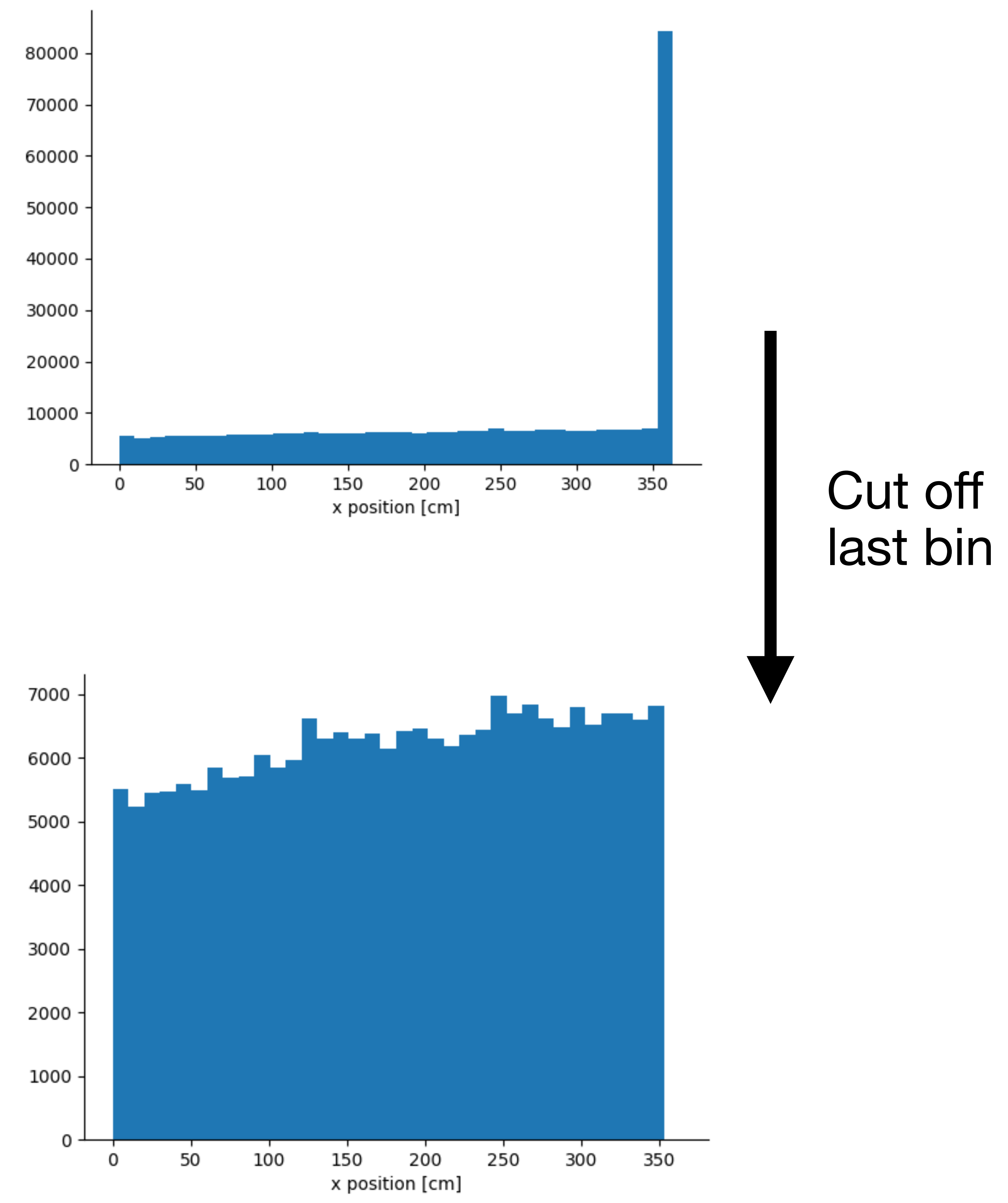
Ion migration model

Decay positions

Isotope	Drift velocity [cm/s]	Ion fraction
Po218	0.43	0.37
Pb214	0.4	0.37
Bi214	0.4	0.56

Distance to the cathode	Fraction of alpha decays [%]
< 30cm	34.72
< 20cm	32.5
< 10cm	30.31

Distribution used as input to simulate ^{40}Ar(α,γ) decay positions



For more details on this study, see *full collaboration meeting talk*

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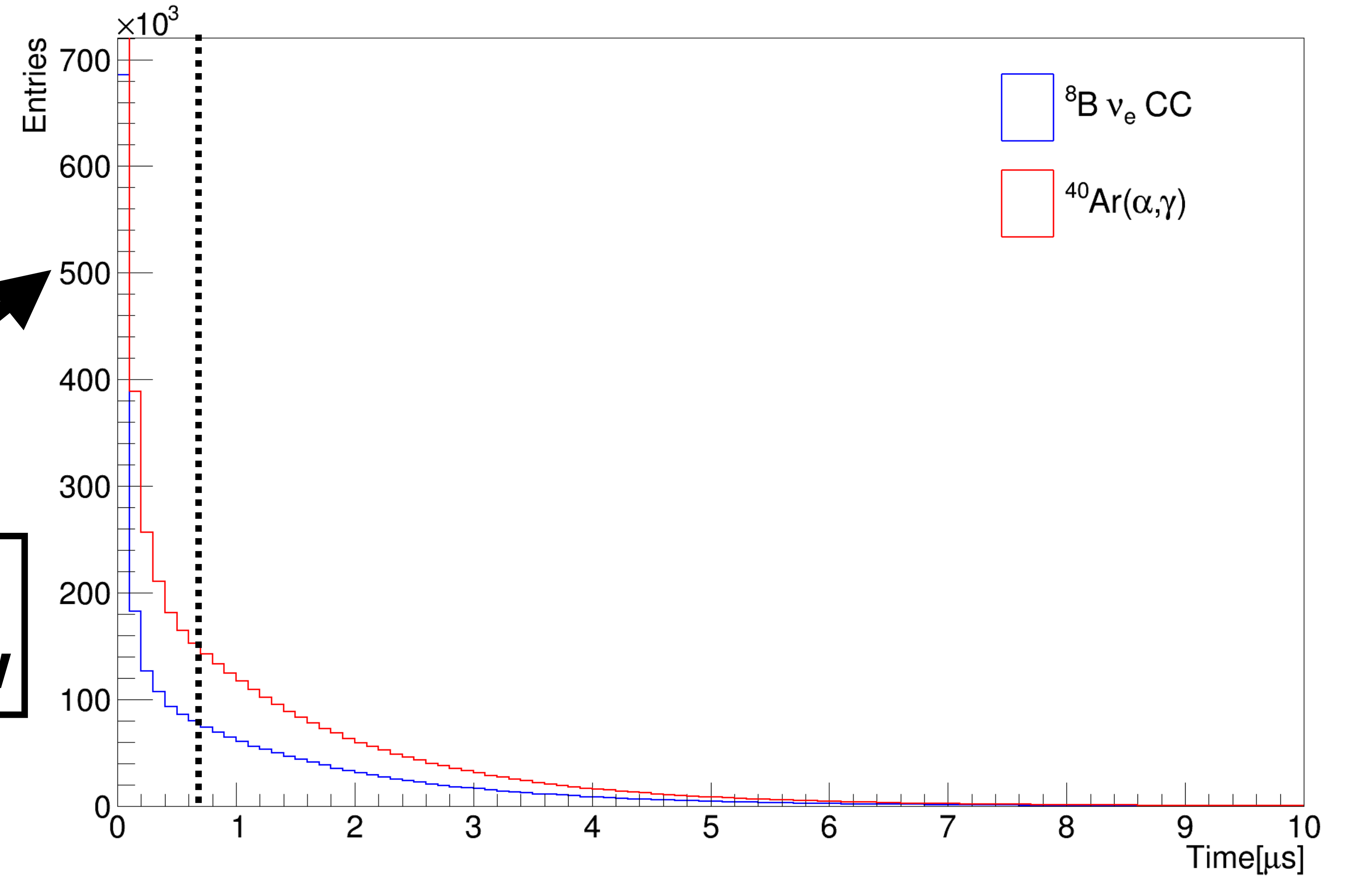
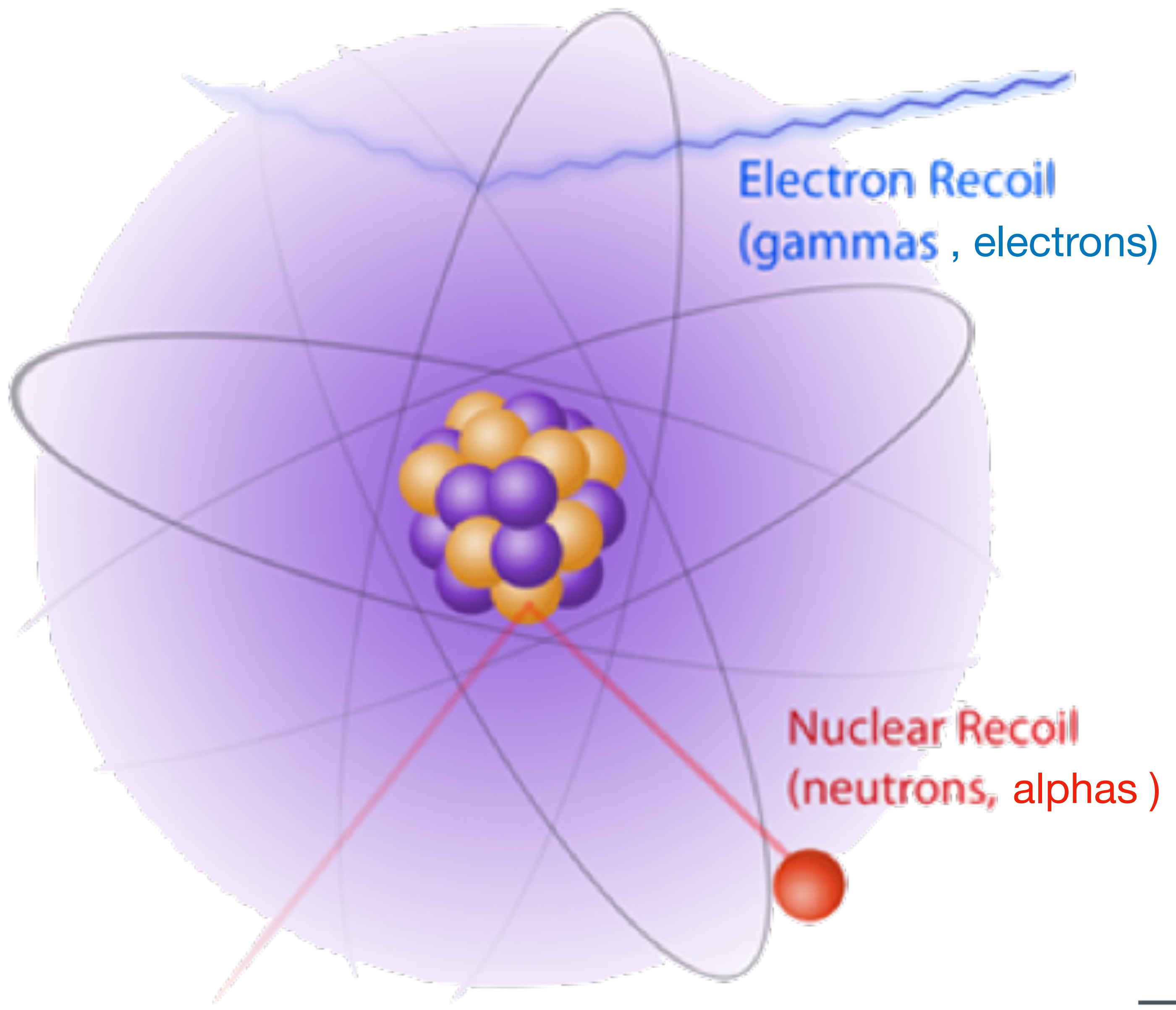
Pulse shape discrimination

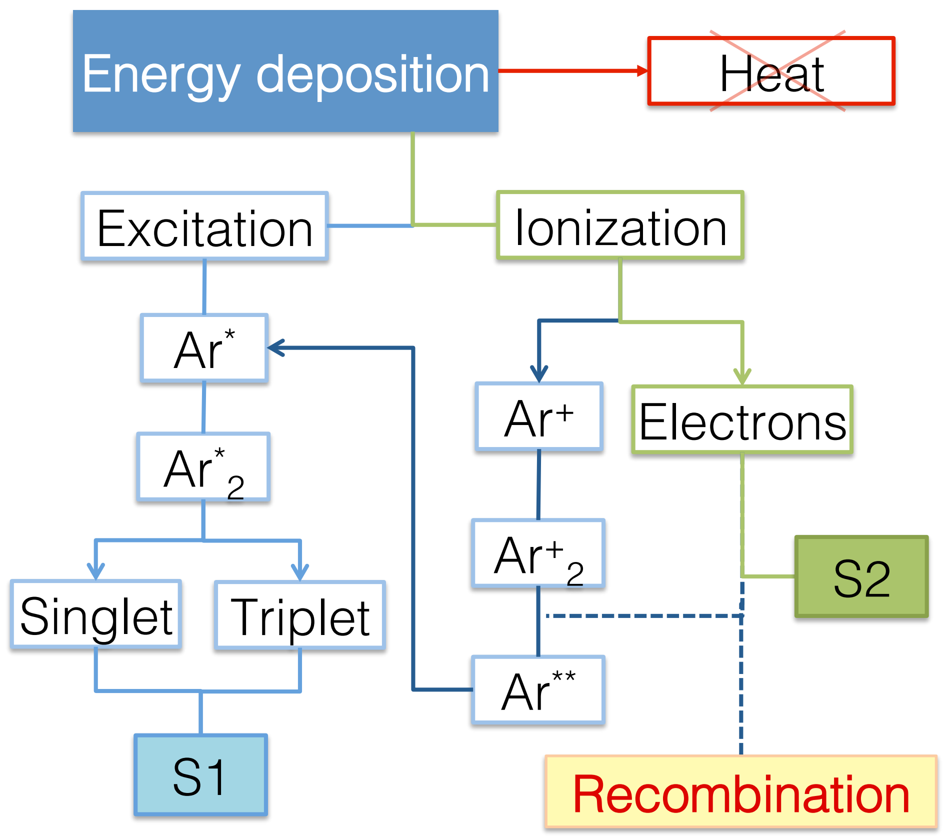
Pulse shape discrimination

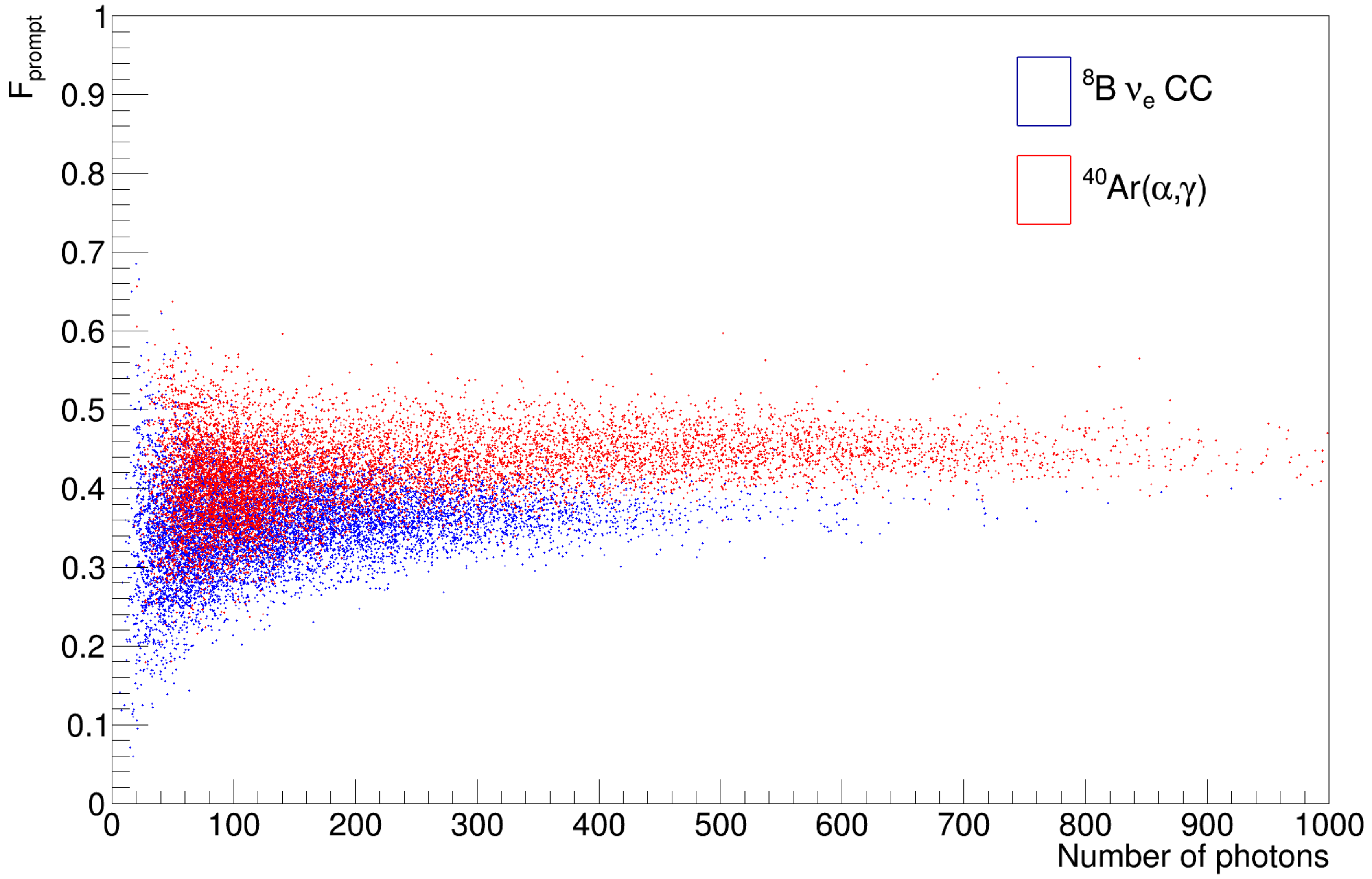
Principle

PSD parameter f_{prompt} :
fraction of light seen in a certain time window









	Singlet	Triplet
Time constant	~7 ns	~1.6 µs
Population ratio for Electron ionizing	33%	67%
Population ratio for Nucleus ionizing	75%	25%

Pulse shape discrimination

Adding reflective foils

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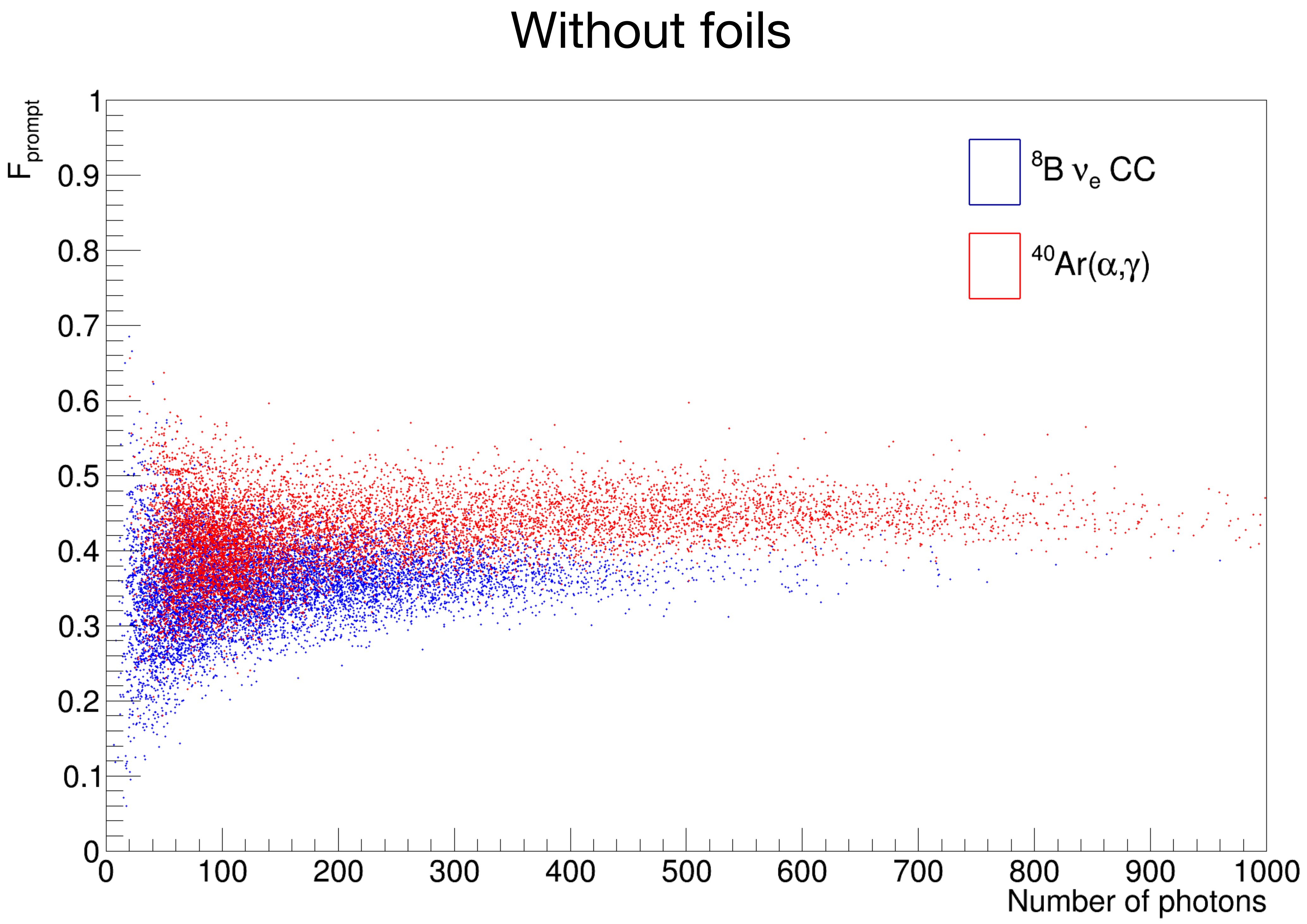
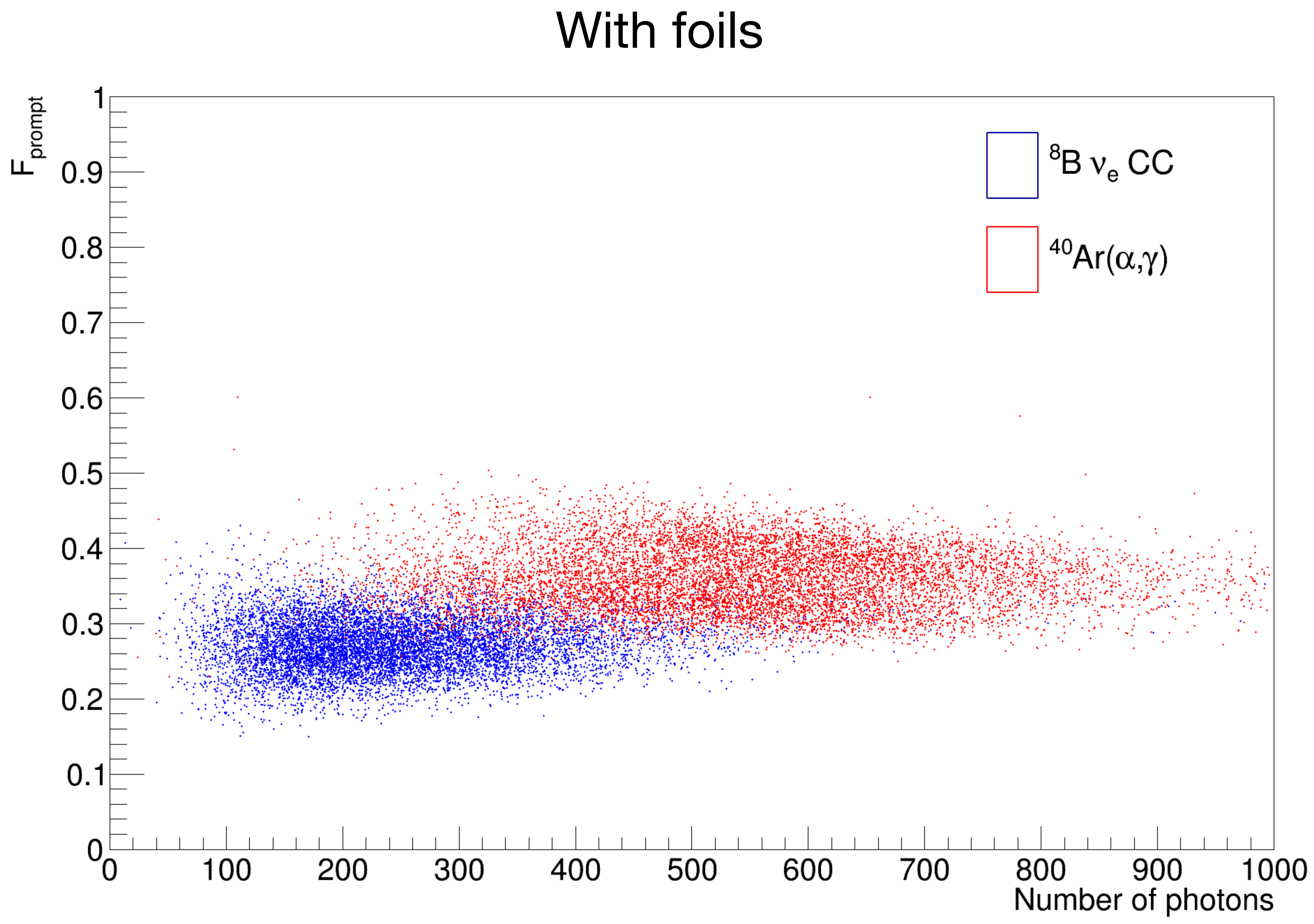




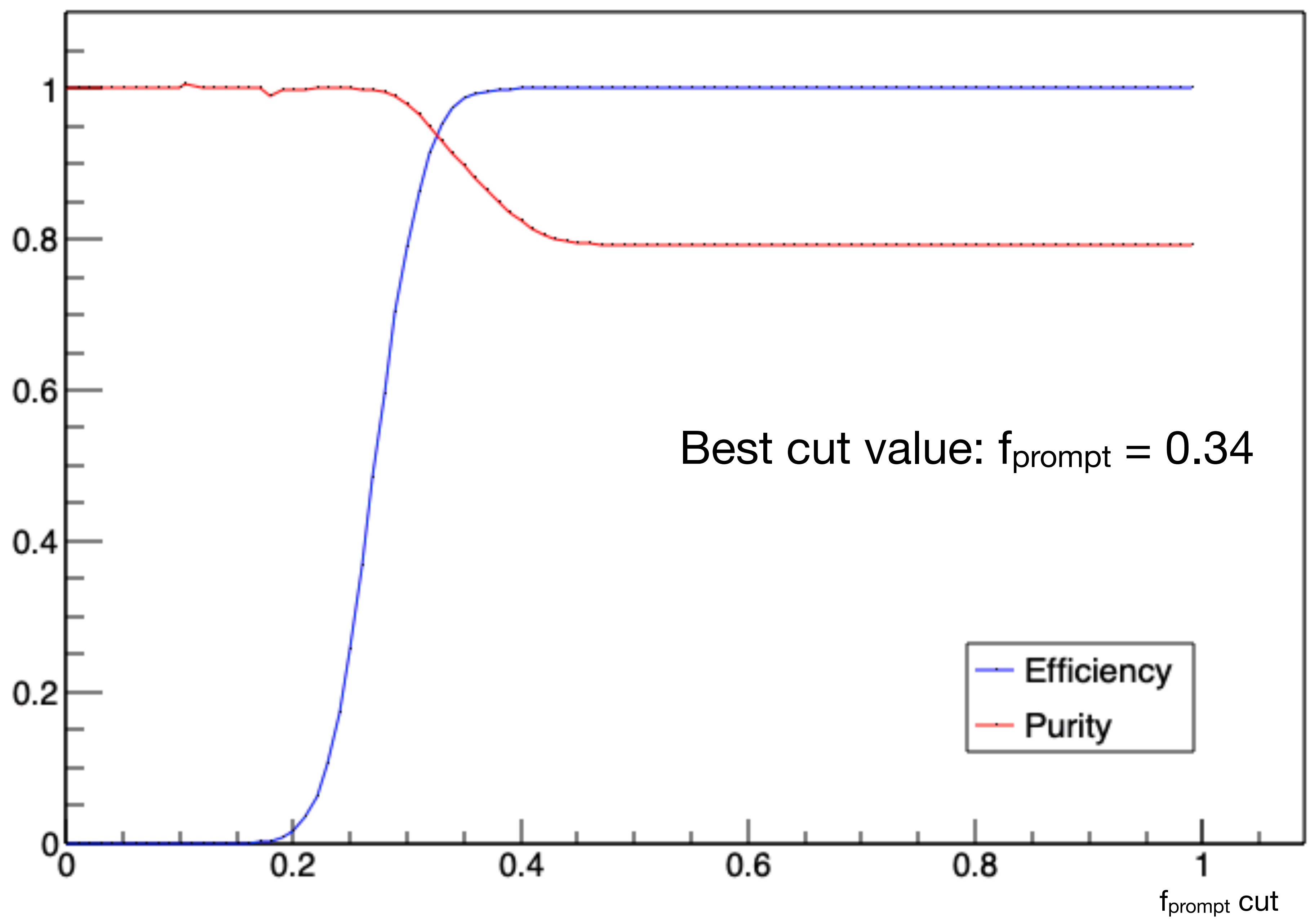
Foils foils improve separation as a large fraction of the ^{40}Ar(α,γ) events happen near the cathode

- Not enough photons collected for efficient PSD without boost from foils

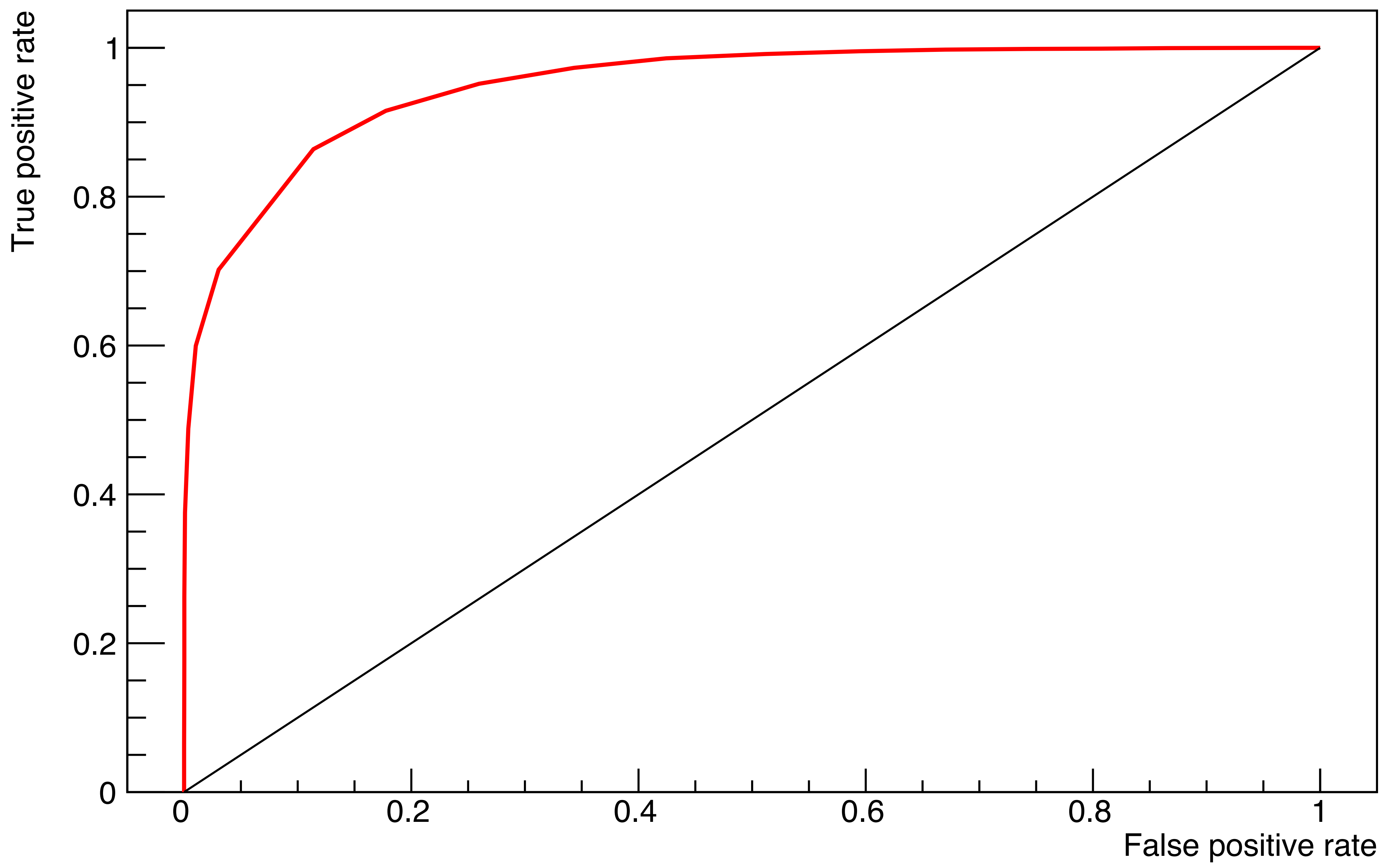
(all subsequent plots will be in the configuration with foils)

Pulse shape discrimination

F_{prompt} cut performance



Efficiency and purity

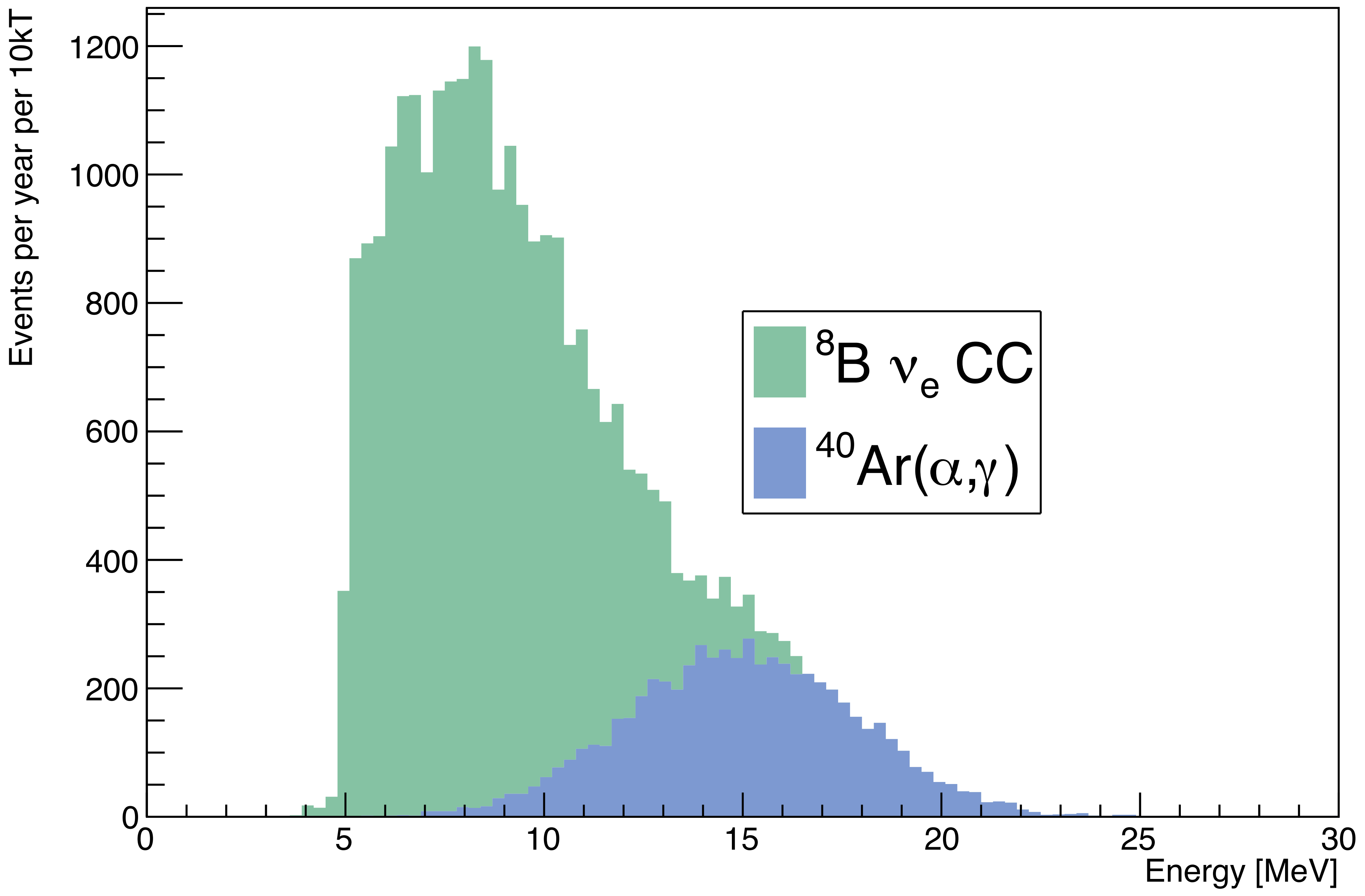


ROC curve

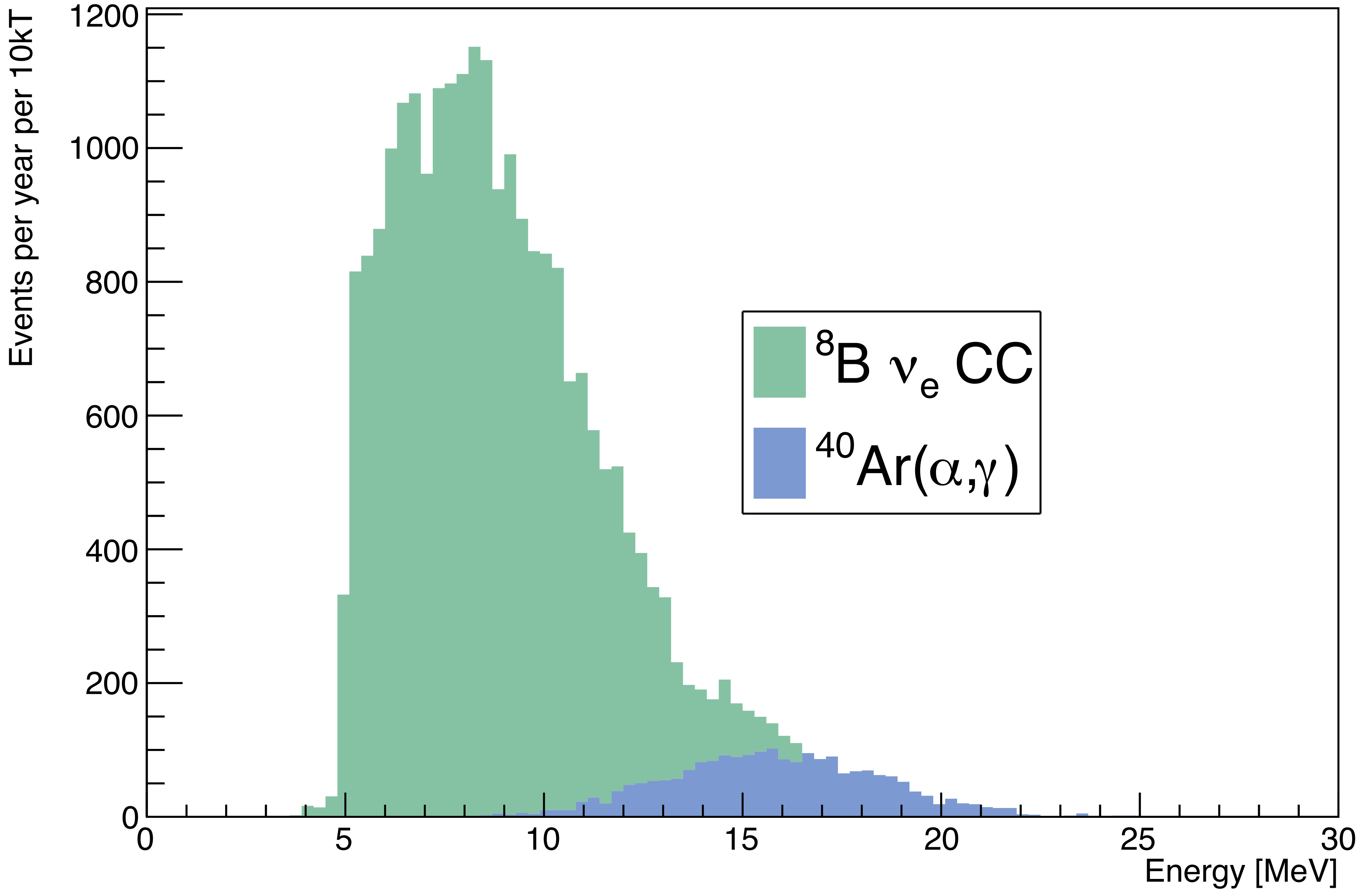
Pulse shape discrimination

Selected events

Signal efficiency: 97.3 %
Sinal purity: 91.5%
Background efficiency: 34.5%



Before f_{prompt} cut

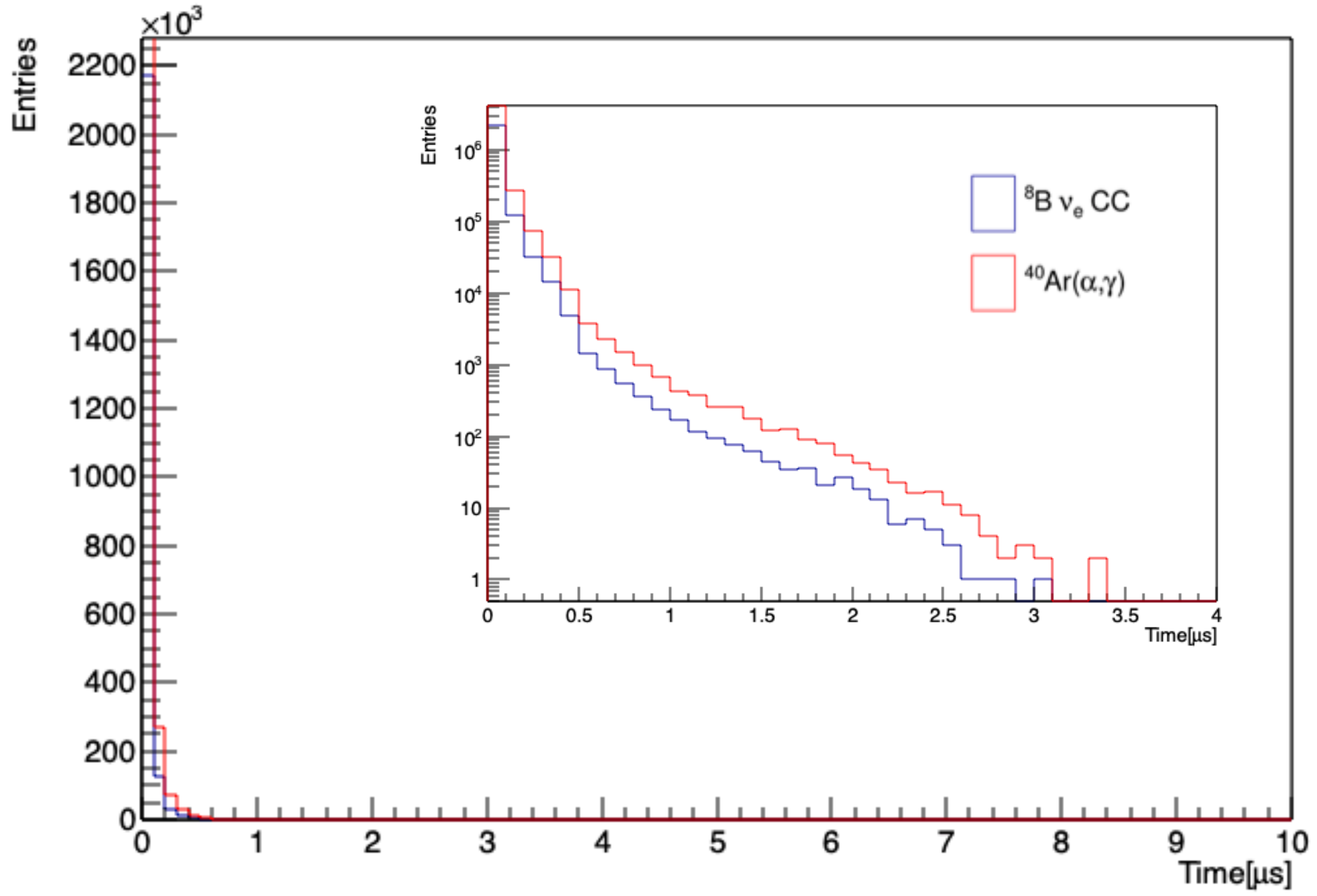


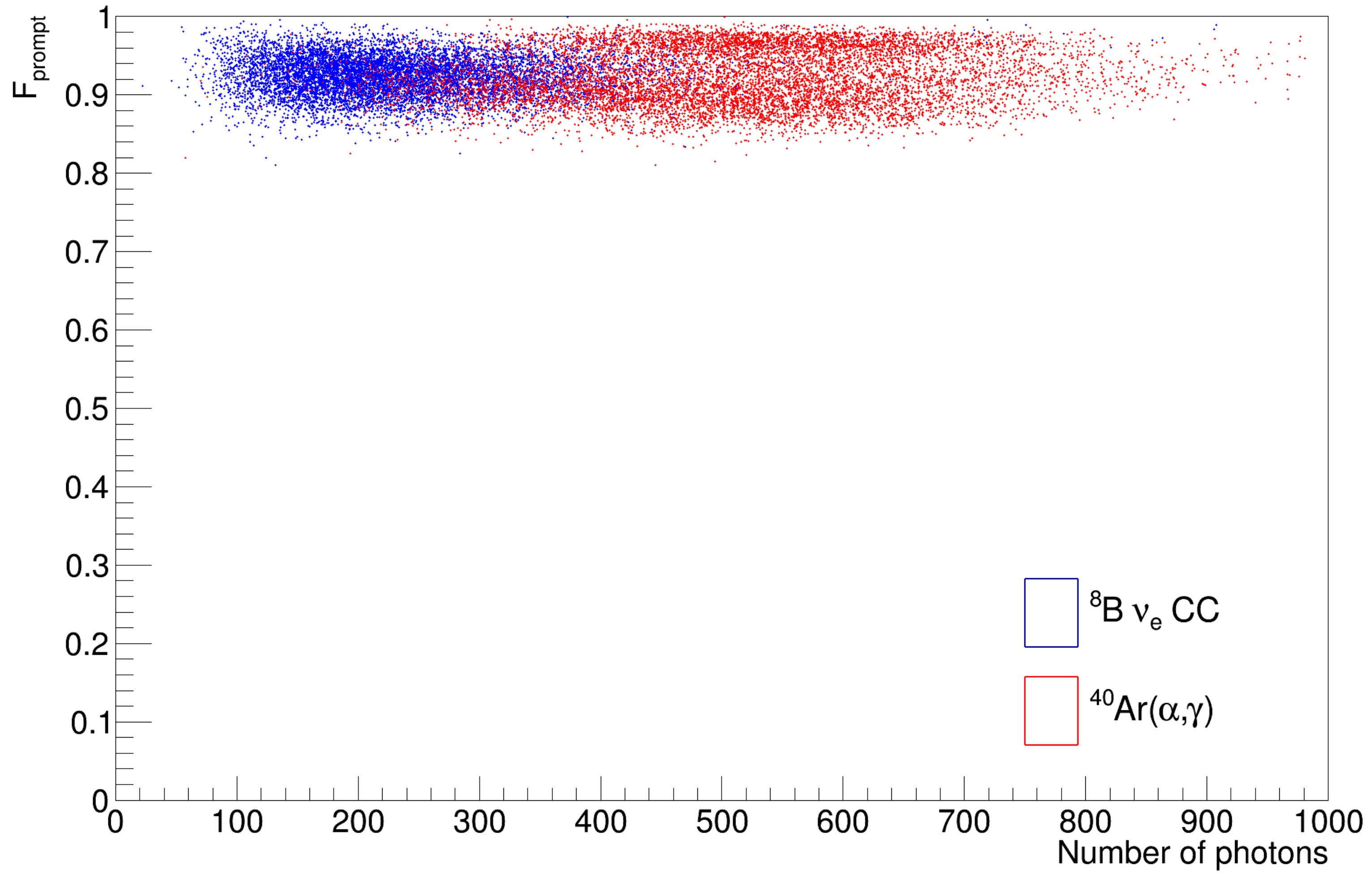
After f_{prompt} cut

Pulse shape discrimination

Adding xenon

- Doping with Xe changes scintillation timings and effectively removes the scintillation slow component
  - ➡ f_{prompt} cut impossible
- Need to find alternative rejection method.
- Accumulation of ^{40}Ar(α,γ) events near the cathode can be used to explore other discriminating observables.





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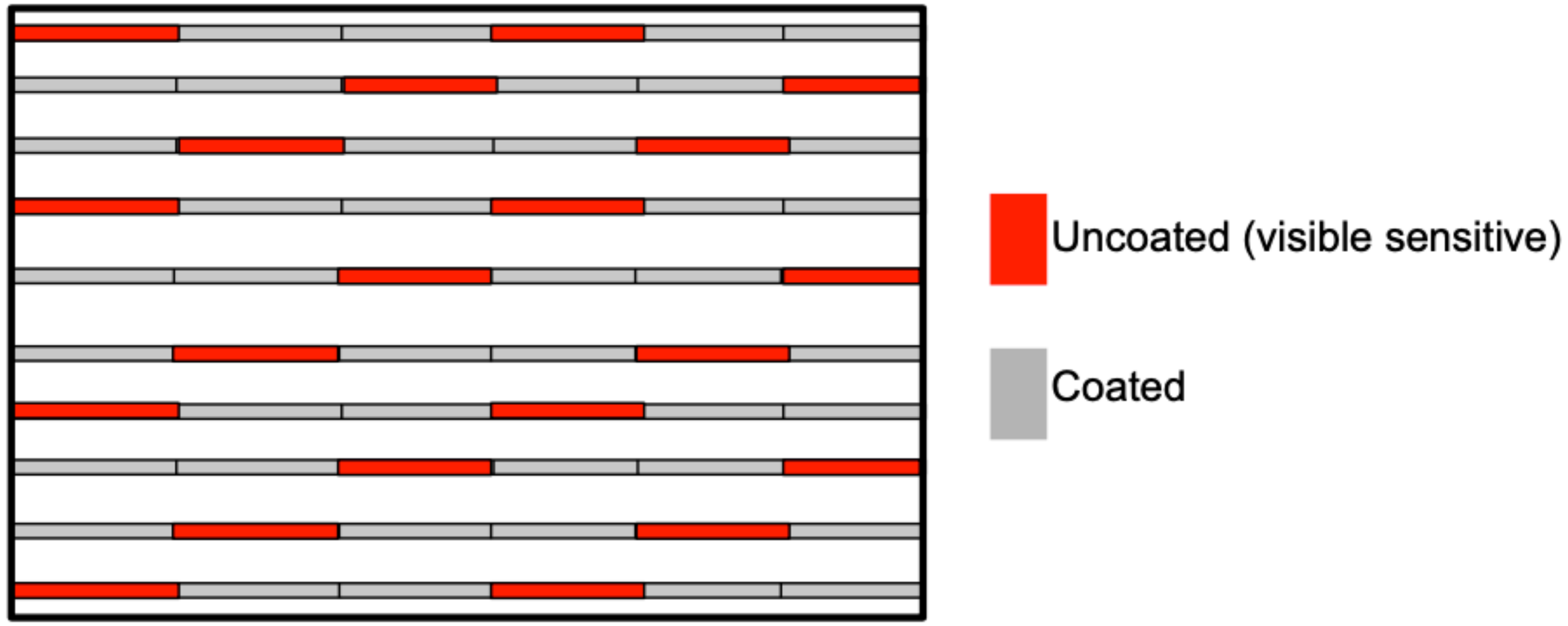
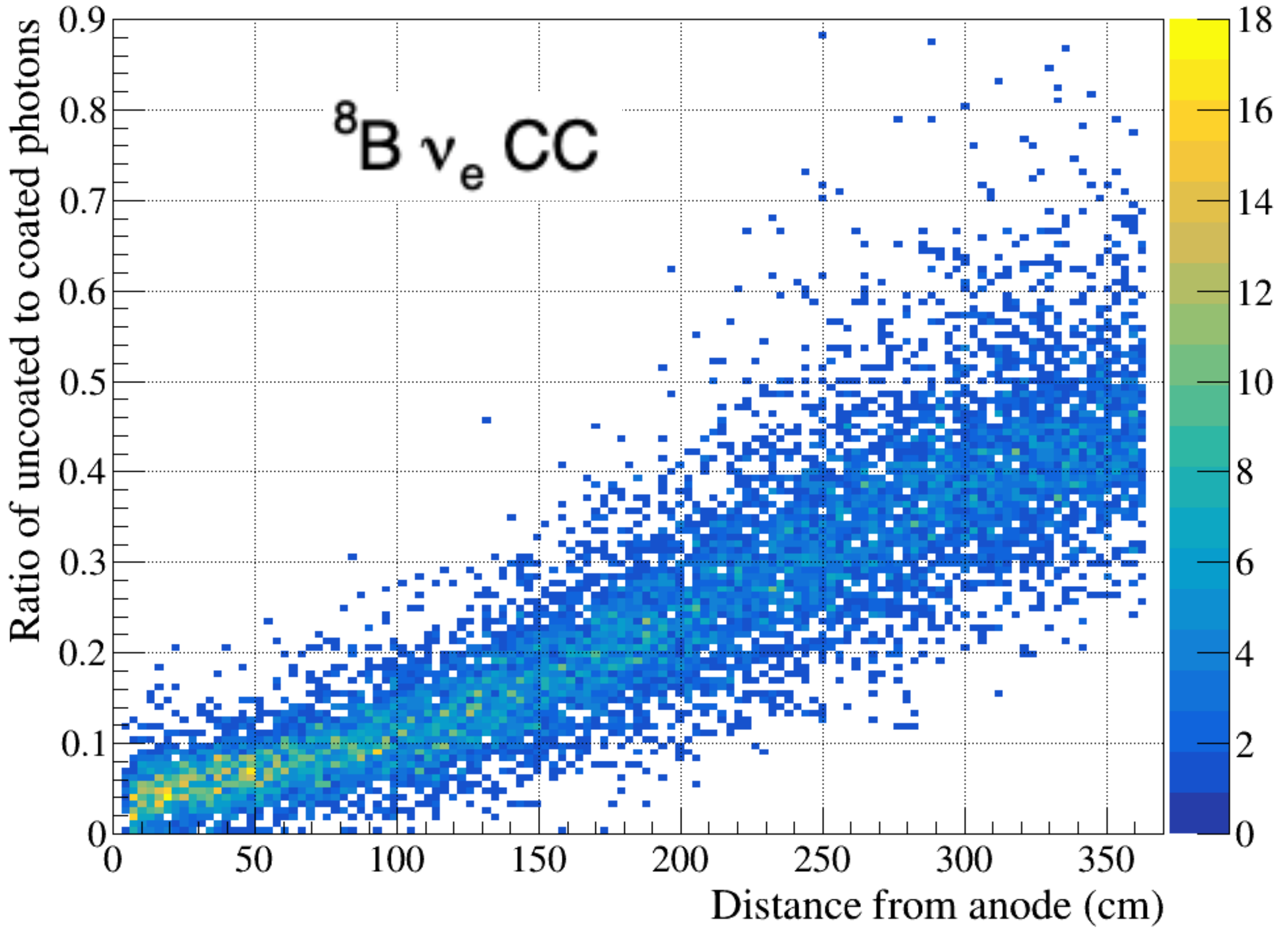
Exploring other methods

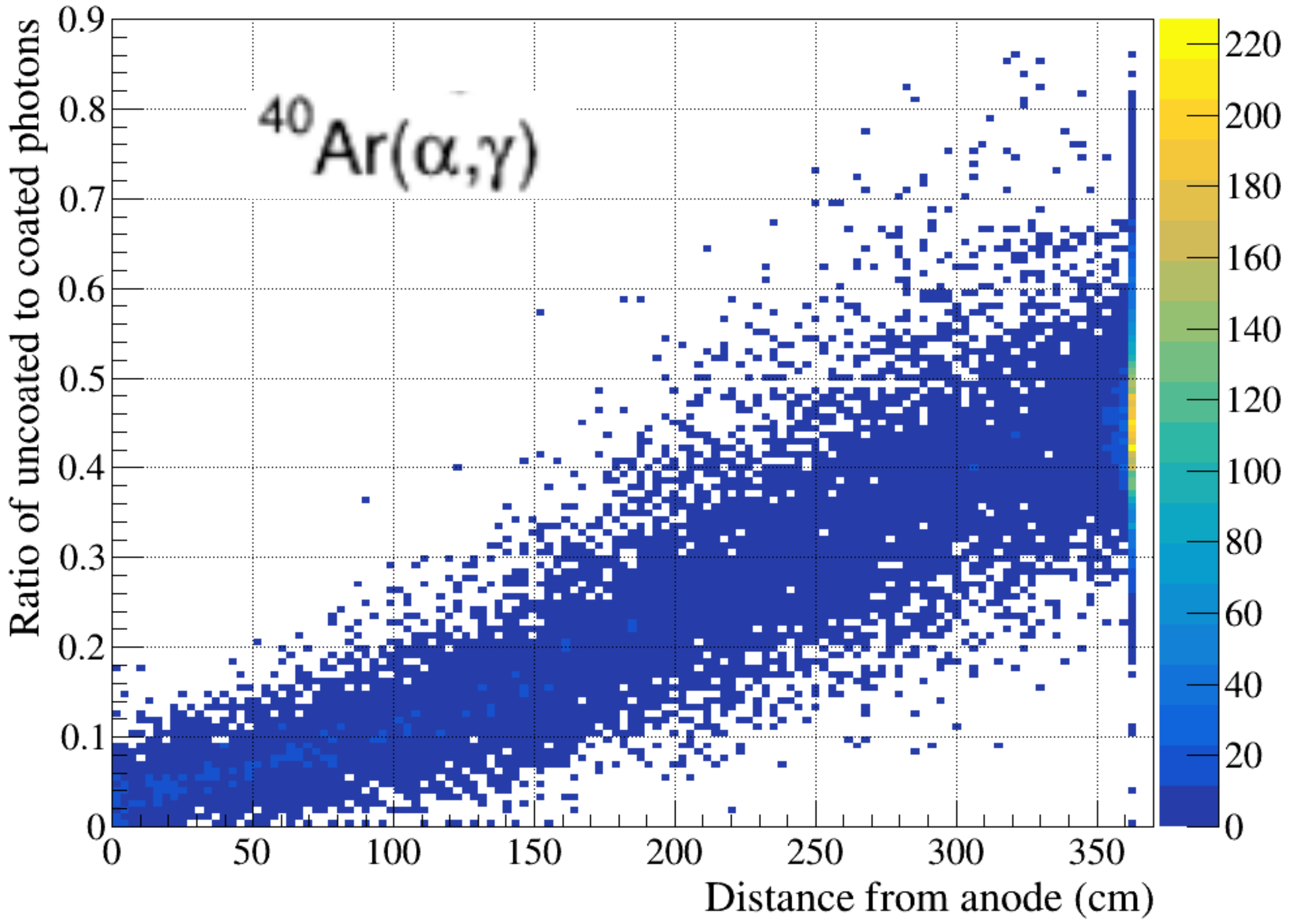
Other methods

Ratio of visible to VUV light

- Have some photon detectors not coated with wavelength shifter.
  ➡ Sensitive only to visible light reflected off of foils
- Coated detectors could be sensitive to both depending on coating
- Events close to CPA will have a higher fraction of visible light detected



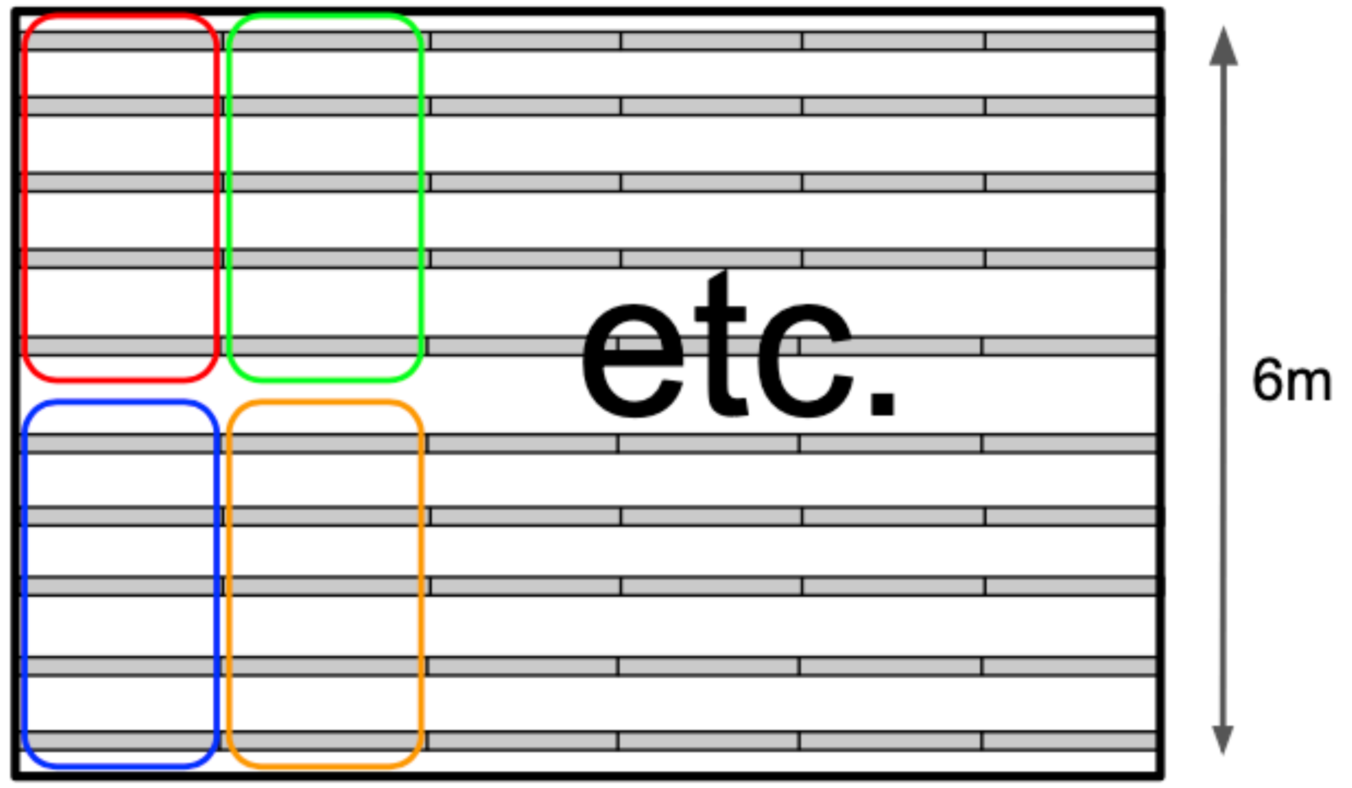


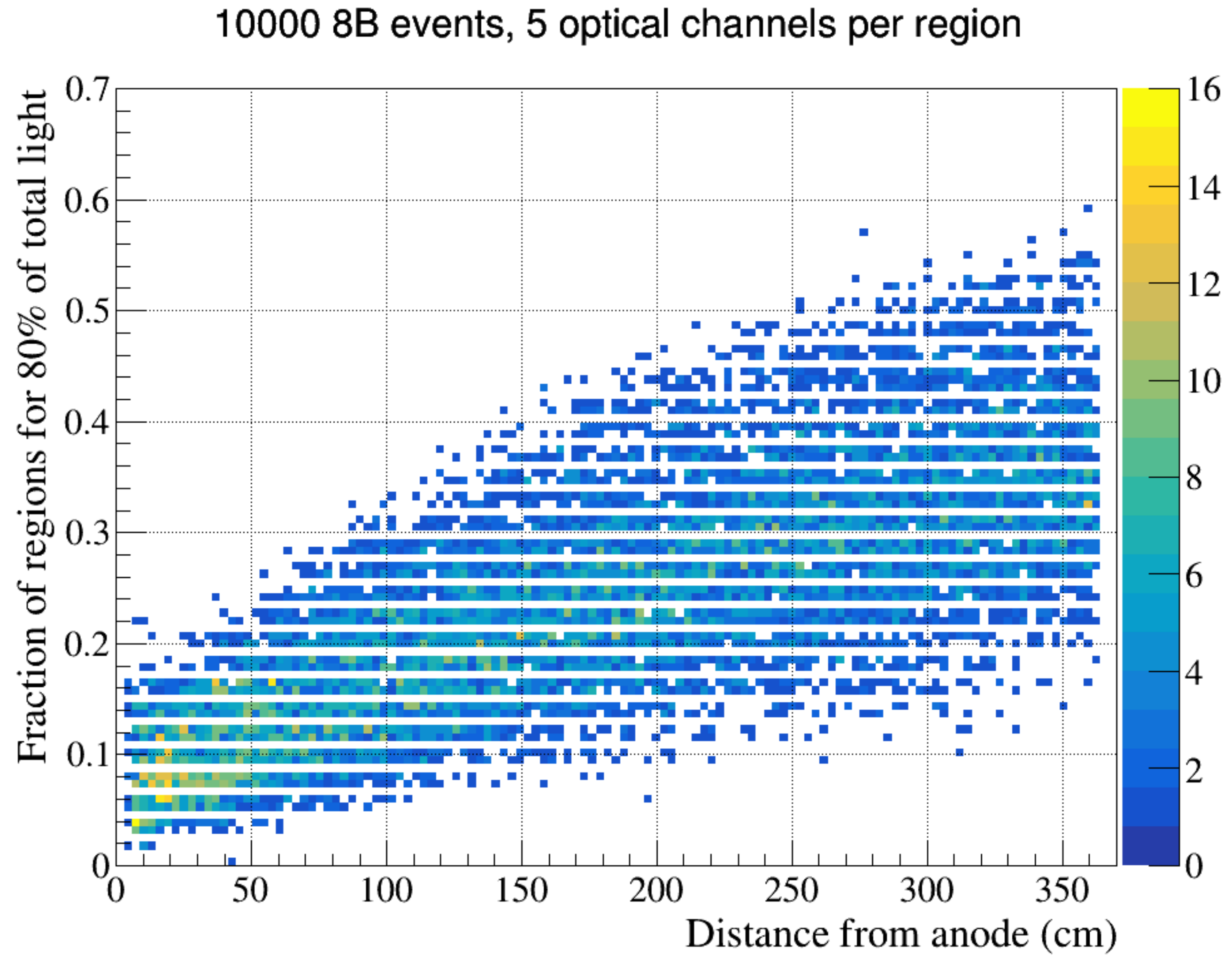


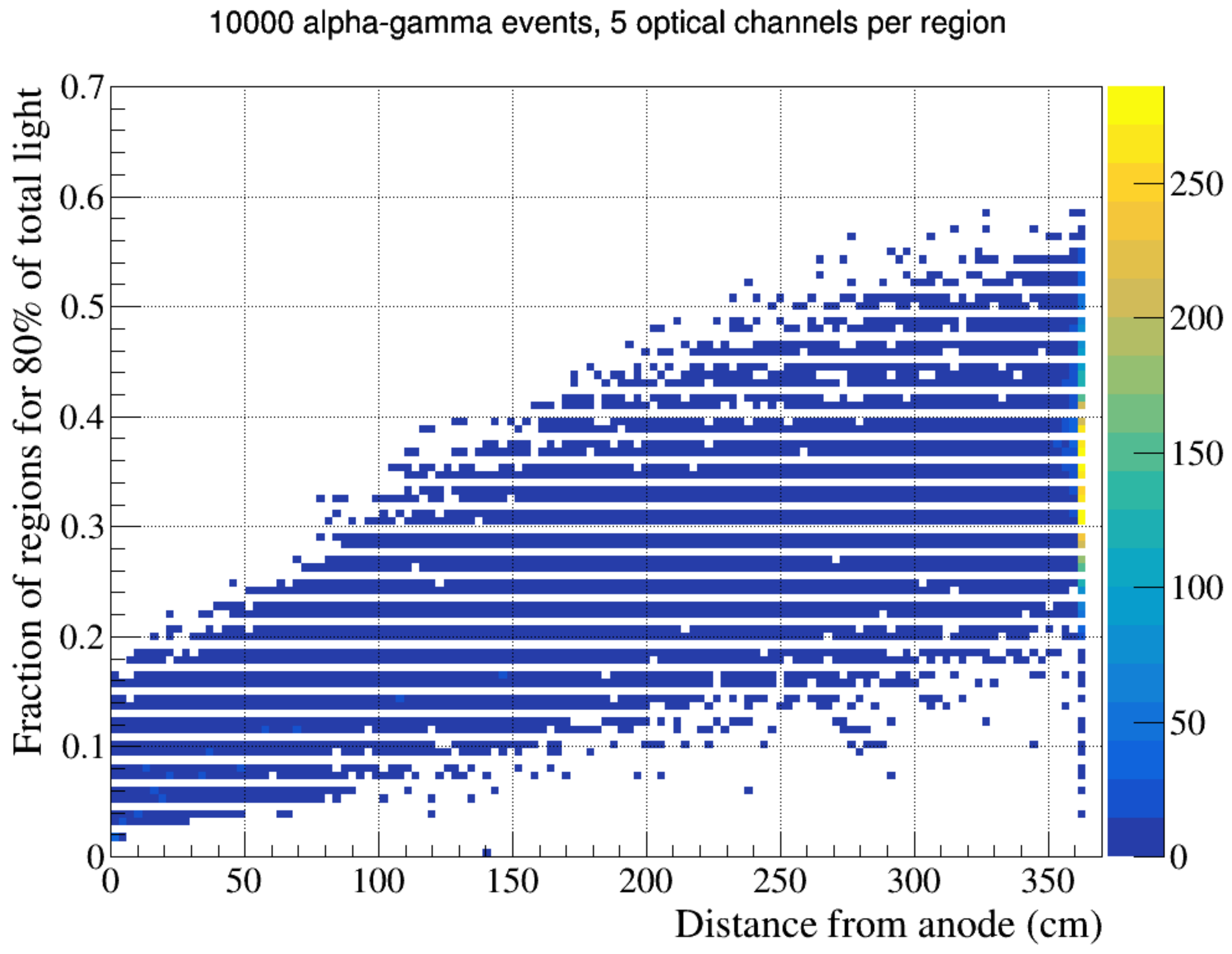
Other methods

Light "spreading"

- Divide the optical detectors into small groups or "regions"
- Record the number of "regions" needed to detect 80% of the total light from an event
- Events close to the CPAs will have a more spread out light pattern
- Can vary number of channels per region to optimise results







Summary and next steps

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- DUNE has great potential for solar neutrinos studies
- ^{222}Rn induced background can be challenging, but scintillation light is a promising way to mitigate it
- Many ideas to be explored:
    - Non-PSD rejection methods to account for Xe doping
    - Combined cuts
    - Tune selection for hep flux
    - Add vertical drift configuration

Thank you!

Questions?